BULLETIN 330

AUGUST 1936

A Study of

Influence of Depth of Ground-Water Level on Yields of Crops Grown on Peat Lands

H. B. ROE

DIVISION OF AGRICULTURAL ENGINEERING

UNIVERSITY OF MINNESOTA

AGRICULTURAL EXPERIMENT STATION

CONTENTS

A STUDY OF INFLUENCE OF DEPTH OF GROUND-WATER LEVEL ON YIELDS OF CROPS GROWN ON PEAT LANDS

H. B. Roe[1]

INTRODUCTION

The Problem

The investigation on which this bulletin is based was inaugurated in the spring of 1925 and extended through the summer of 1930 to determine the degree of drainage that produced the best practical results with field and horticultural crops commonly grown in this state.

Drainage requisite.—Drainage is a prime requisite in the agricultural use of peat soils except for aquatic and semi-aquatic plants such, for example, as reed canary grass.

The summer frost factor.—Experience in Minnesota has shown that frosts may occur in any month of the year on peat areas. This is a very serious problem as most of the peat lands under cultivation are devoted to the production of truck crops peculiarly liable to damage by frost. While a complete discussion of the frost hazard is outside the exact scope of this bulletin, some consideration of it is inseparable from the production problem on peat areas, especially as it is affected by drainage.

As this fact was recognized, provision was made, in the course of these tests, for securing continuous temperatures of the peat soil at depths of 0.3, 0.8, 2.0, 3.0, 4.0, and 5.0 feet below the bog surface, on the 1-, 3-, and 5-foot controls, and also in the air at the surface and one foot above the surface at these same stations and at one point on the high, mineral soil ridge just north of the bog. Table 1 gives the monthly maximum, minimum, and mean temperatures in air, from May to October, inclusive, for the period of these tests from the official government record at Chaska, and the local record as secured at the experimental tract for the last 4 years of this period, together with a statement of the variations of the latter from the Chaska record. Table 2 shows the dates and air temperatures when frosts occurred on the bog from June 1 to September 30 of each year, 1927 to 1930, inclusive.

Verifying earlier experience by the author (8), these records showed the following facts. Mineral soil is a much better conductor of heat than is peat, and wet peat is a much better one than is dry peat. A

[1] In the preparation of this bulletin acknowledgements are due the following men: To A. C. Arny and F. W. McGinnis, of the Division of Agronomy and Plant Genetics, and to F. A. Krantz, H. P. Traub, and T. M. Currence, of the Division of Horticulture, for their valuable contributions of data; to Messrs. Arny and Krantz, and to J. H. Neal, of the Division of Agricultural Engineering, for their critical, constructive reading of the manuscript; and to O. W. Howe, of the Division of Agricultural Engineering, for his effective preparation of the illustrations.

Table 1.—Monthly Temperatures

Month	Station	1925 Max.	1925 Min.	1925 Mean	1926 Max.	1926 Min.	1926 Mean	1927 Max.	1927 Min.	1927 Mean
May	Chaska	98.	25.	54.3	89.	29.	61.6	83.	38.	55.9
	Exp. tract							88.1	27.6	55.9
June	Chaska	92.	41.	66.0	96.	36.	63.2	96.	35.	64.9
	Exp. tract							109.3	27.6	66.0
July	Chaska	95.	45.	69.4	103.	44.	71.8	94.	26.	68.6
	Exp. tract							102.8	37.0	70.8
August	Chaska	93.	45.	70.9	99.	48.	68.8	89.	38.	66.3
	Exp. tract							106.3	27.6	67.1
September	Chaska	100.	37.	64.8	88.	28.	57.3	91.	32.	62.9
	Exp. tract							101.8	24.1	65.9
October	Chaska	62.	6.	36.5	74.	19.	45.5	81.	25.	51.0
	Exp. tract							91.7	17.6	51.0

Month	Station	1928 Max.	1928 Min.	1928 Mean	1929 Max.	1929 Min.	1929 Mean	1930 Max.	1930 Min.	1930 Mean
May	Chaska	89.	32.	61.3	88.	24.	54.6	87.	29.	59.0
	Exp. tract	94.9	27.1	61.3						
June	Chaska	84.	36.	62.8	94.	41.	65.0	92.	43.	68.0
	Exp. tract.	91.5	26.6	63.7	95.9	31.0	63.0	94.4	31.8	65.6
July	Chaska	95.	49.	72.4	96.	43.	73.8	100.	42.	74.4
	Exp. tract	106.8	42.1	75.7	99.8	33.3	70.0	99.4	32.5	70.6
August	Chaska	93.	39.	70.0	93.	44.	69.5	99.	45.	72.5
	Exp. tract	108.5	30.5	71.4	95.0	34.3	66.9	99.4	33.3	69.1
September	Chaska	81.	25.	58.4	95.	26.	59.6	86.	28.	61.0
	Exp. tract	92.0	18.1	58.8	95.0	22.1	57.6	92.0	22.0	59.2
October	Chaska	91.	17.	51.0	79.	27.	49.1	84.	15.	46.8
	Exp. tract	93.5	17.0	51.0	79.0	22.6	49.1			

Average Monthly Variation of the Experiment Tract Record from the Chaska Record

Month	Maximum	Minimum	Mean	Number of years averaged
May	+5.5	− 7.7	0.0	2
June	+6.3	− 9.5	−0.6	4
July	+6.0	− 3.8	−0.5	4
August	+6.3	−10.1	−1.0	4
September	+7.2	− 5.9	−0.1	4
October	+4.7	− 3.9	0.0	3
Weighted average all months	+6.1	− 6.9	−0.4	

mineral soil or a wet peat, therefore, gives up heat to the atmosphere lying next to it much more rapidly than does dry peat under similar local weather conditions. During the night the cooler air from the upper atmosphere, displacing the warm currents rising from the mineral soil adjacent to the bog, settles down over the lower lying bog surface. As this process continues through a cool night, progressively lower temperatures tend to occur in the zone of the atmosphere lying next to the bog surface as we go from the areas of shallower ground-water level to those of deeper ground-water level. This is because the more moist peat on the higher controls gives up heat to the adjacent atmosphere more rapidly than does the drier peat on the lower controls.

On the experimental tract the result of this condition was that, on nights not sufficiently cool for any danger of frosts on the mineral soils, frosts did frequently occur on the peat bog and with increasing intensity, going from the shallower to the deeper controls.

This tendency to summer frosts undoubtedly had a deleterious effect on the yields, except those of timothy and clover, reported on the deeper controls in these tests, particularly in the case of all crops especially subject to frost injury.

Table 2.—Summer Frosts*

(June to September, Inclusive, Temperatures One Foot in Air)

1927		1928		1929		1930	
Date	Lowest for day	Date	Lowest for day	Date	Lowest for day	Date	Lowest for day
June 1	29.4	June 2	31.0	June 3	31.7	June 8	31.8
June 5	27.6	June 3	27.0	June 8	31.0		
June 6	30.5	June 4	32.1				
		June 10	27.5				
July		July		July		July 14	32.5
						July 15	32.6
Aug. 9	27.6	Aug. 31	30.5	Aug.			
Aug. 24	29.4						
Sept. 22	31.0	Sept. 18	30.5	Sept. 5	31.7	Sept. 2	29.2
Sept. 23	24.1	Sept. 23	31.0	Sept. 14	31.0	Sept. 3	32.3
Sept. 24	28.8	Sept. 26	18.1	Sept. 16	30.9	Sept. 4	28.8
		Sept. 27	31.6	Sept. 18	21.6	Sept. 6	31.4
		Sept. 28	30.1	Sept. 19	22.6	Sept. 15	33.0
		Sept. 29	26.1	Sept. 20	22.6	Sept. 18	31.1
		Sept. 30	26.5	Sept. 30	26.6	Sept. 20	31.2
						Sept. 22	31.0
						Sept. 25	30.5
						Sept. 28	32.1
						Sept. 29	22.6
						Sept. 30	22.0

* No record for 1925 and 1926.

Influence of air-drainage.—General observations of air-drainage conditions in the neighborhood of the bog, such as wind direction in relation to location of lanes of clearing through the surrounding timber, indicate that good air-drainage is essential for effective protection against summer frosts. It was noted that prevailing wind at times of frost occurrence was almost invariably northwest. This drove the cold air down over the bog where it settled as in a bowl without any outlet, as the solid wall of timber to the south and east of the bog practically stopped air movement in the layers of air near the ground over the southern half or two-thirds of the bog. Since the close of these tests nearly all the timber to the south and west has been cleared off and the less frequent occurrence of untimely frosts is a very noticable result, evidently because air movement from the north and west over the bog is no longer interrupted.

Contributions of Other Investigators

A great deal of experimental and research work has been done by other investigators, on the cropping of peat lands, both in this and in foreign countries.

Ghostly (5) points out that good air drainage over peat land is absolutely necessary if untimely frosts are to be avoided. He suggests that outlet ditches will serve well as air drainage lanes when the waste banks are spread or are cut through at frequent intervals. He further points out that the frost hazard may be greatly lessened also by the following practices:

1. Rolling the surface with a heavy roller. (This contention is supported, also, by Whitson and Ulsperger (9) because packing the soil makes easier the absorption of heat by it.)
2. Heavy fertilization to secure rank growth.
3. Spacing rows close together (2 feet for potatoes[2]) so that the vines will cover the ground and hold the warm air.

Robertson (7) holds that where annual rainfall is high (nearly 50 inches) as at Stornoway, Scotland, maintaining a given water level is not essential, but on the European mainland and especially in Scandinavia, where the annual rainfall is only 25 to 32 inches, the following different ground-water levels were found desirable during the growing period.

Crop	Depth of water table in feet
Hay	1¼ to 1½
Pasture	1¾ to 2¼
Cultivated crops	2¼ to 2¾

For these results the drains were placed 60 feet apart on deep peat, and 3 to 4 feet deep, the water being raised by means of sluice gates.

Such other contributions as are especially noted herein are referred to in the customary manner in those sections of the text to which they are particularly related. For the convenience of the reader a list of all references used is appended.

Organization and Co-operation

The project was organized by the Division of Agricultural Engineering, and the work was carried out in co-operation with the Division of Agronomy and Plant Genetics and the Division of Horticulture, but each division framed its own separate project. The Division of Agricultural Engineering assumed the responsilibity for the design, installation, and care of all engineering features, the maintenance and recording of the ground-water levels, and the securing of rainfall and temperature records. The Division of Agronomy and Plant Genetics assumed charge of the preparation of the seedbed, including fertilization, and the planting, care, harvesting, and securing of yield and quality records of all the field crops. The Division of Horticulture assumed similar responsibilities for the vegetable crops.

LOCATION AND DESCRIPTION OF EXPERIMENTAL TRACT

The tract chosen for these tests was a portion, about 2½ acres in area, of a high-lime peat bog located, as shown in Figure 1, in Hennepin

[2] The statement in Ghostly's paper is 3 feet but it should have been 2 feet.

County a few miles west of Minneapolis and close to Lake Minnetonka, which lies to the north and west of it.

The surrounding area is morainal in character. The surface is rolling and on most of the hills and ridges the soil is a sandy loam while in most of the valleys and pockets there is peat. The experimental tract is located near the edge of one of the peat areas.

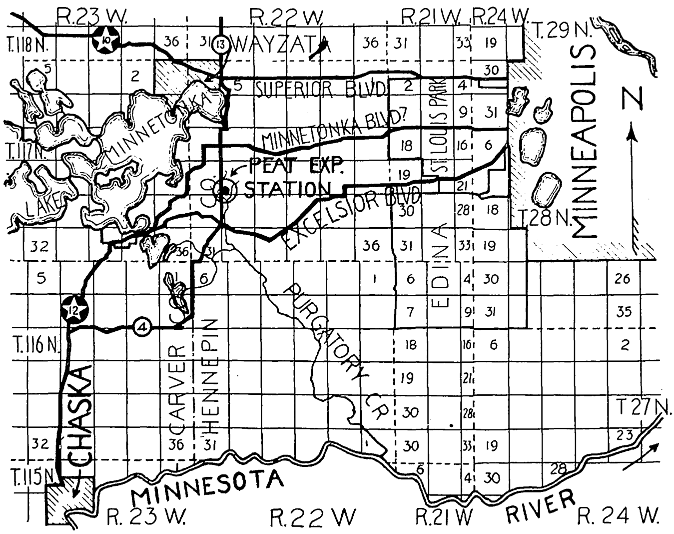

FIG. 1. MAP SHOWING LOCATION OF EXPERIMENTAL TRACT

Soil.—The surface soil of the tract is a high-lime peat. An analysis, by the Division of Soils, of a composite sample collected from an unfertilized portion of the bog in 1922 gave the following:

Ash	26.74%
Nitrogen	2.58%
Phosphoric acid (P_2O_5)	0.61%
Lime (CaO)	4.04%

The comment was appended to the analysis that one may expect a marked response to applications of potash and a much smaller effect, if any, from applications of phosphate, while, with the abundance of lime present, the nitrogen will be readily available.

The soil of the tract was originally raw, coarse, and fibrous, but 3 years' tillage of the bog that had occurred from 1922 to 1925 had reduced its surface, to plow depth at least, to a firm, finely divided, well decomposed condition.

Subsoil conditions.—About the east two-thirds of the east half of the one-foot control area (see Fig. 2) is underlaid by a medium-fine white quartz sand at a depth of 1½ to 3 feet. This sand bed also extends southward under the 2-foot control, still sufficiently near the surface under the east half seriously to hamper the control of the ground-water table at the 2-foot depth. From this point south the sand deposit dips rapidly under the peat over the 4-, 5-, and 6-foot controls where early soundings indicated peat of a great depth. A change in depth of tile lines in 1928, however, showed marl at a depth of 3½ to 4 feet below the surface on the east half and from 4½ to 7½ feet below the surface on the southwest quarter of the tract.

THE WATER CONTROL SYSTEM

Source of water supply.—The source of water supply was a large tile submain of a judicial ditch, which throughout the year carries ample water to insure at all times a supply which can be regulated by a dam within the submain at the take-off well.

Design.—A practical index to the degree of drainage is the average depth of the ground-water surface below the surface of the bog. Therefore, to secure definite areas on the experimental tract on which the ground-water surface could be maintained at specific depths, the tract was laid out as shown under *plan* in Figure 2. There were 6 control plots, each 2 rods wide and of a length equal to the total width of the experimental tract. Each control plot was surrounded by a loop of 5-inch drain tile laid with rather open joints, at depths of 4½ to 6½ feet according to the control plot and with a decided down grade on each loop toward the main. Each plot was separated from the next plot on either side of it by a transition plot also 2 rods wide. The loops of 5-inch tile each started from and ended in the 8-inch main drain of sewer pipe. This main drain lay in the north and south center line of the tract and had tightly cemented joints but opened freely into each control-weir box hereinafter described.

The north end of the tract is the high end. The flow of the water is, therefore, to the south. By means of the control weirs, later described, the ground-water level on each control plot was kept, theoretically, at the average depth desired, as the weirs held the loop tile filled with water under natural hydrostatic pressure and this water made its way through the joints of the tile out into the surrounding soil to a height closely approximating the level of the weir crest of the control weir for each plot.

The original grade of the main tile was uniformly 0.25 per cent, but the settlement of the tile in the soft bog made the final grade somewhat irregular as shown in the *profile* in Figure 2. However, even after settlement, there was sufficient grade to carry the water with ample velocity. The original depth of the main was about 5½ to 6 feet. Owing to a general rise of the ground-water level in the region in 1928, coupled with settlement of the bog surface discussed elsewhere in this bulletin, it was found necessary, that season, to lower the main tile and the 5-inch loops on the 3 deepest controls, as shown in profile in Figure 2.

Theoretical depths of water table.—From 1925 to 1928 the theoretical depths of water table on the different control plots beginning at the north end were 1 foot, 2 feet, 3 feet, 4 feet, and 5 feet. The most southerly control plot noted in Figure 2, the 5-foot control area, was not added until 1929 and a 6-foot control depth was never obtained.

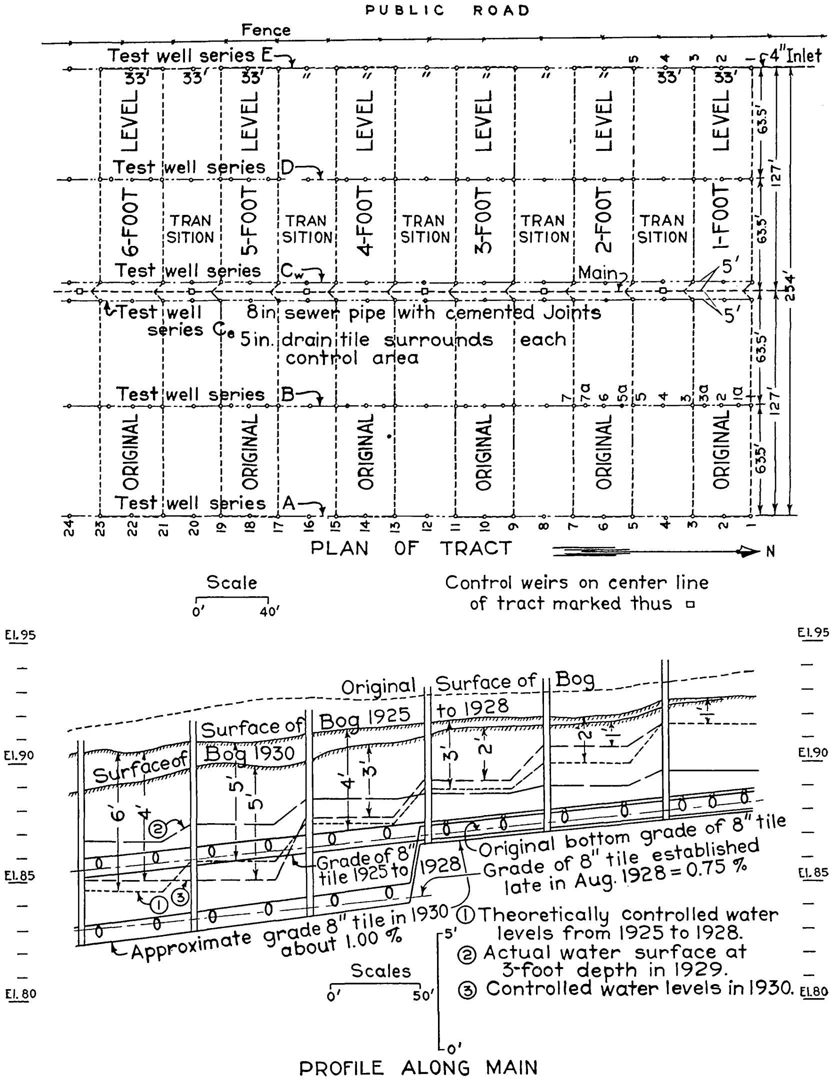

Fig. 2. Plan and Profile of Experimental Tract Showing Layout of Control Zones and Theoretical Control Levels

In 1929 the water table was held theoretically 3 feet below the bog surface over the entire tract as a check on yields of previous seasons, as some of the co-operators believed that variations in yields obtained in previous years with the water table at different depths on the different controls might be owing mainly to other factors than differences in ground-water level. Results obtained in 1929 did not seem to support this belief.

In 1930, the last year that cropping tests were run, subsoil conditions and the regional rise in the ground-water level already mentioned forced the following order of theoretical control plots. The original one-foot control plot was ignored except in as far as it might serve as a check on the new one-foot control plot. The former 2-, 3-, and 4-foot control plots became the 1-, 2-, and 3-foot control plots, respectively. The original 5-foot control plot was retained as such and the old previously unused 6-foot control plot was made the 4-foot control.

Influence of the marl subsoil on the control of the ground-water levels.—A deposit of marl in its original, undisturbed bed almost completely obstructs the passage of water so that underdrainage of a marl subsoil is practically impossible. The discovery of marl so near the surface on the east half, therefore, made it clear why in preceding seasons it has been impossible to maintain the water table at the theoretical depth on the 4- and 5-foot controls. It was the height of the marl subsoil coupled with the further settlement of the bog following the change in the depths of the tile lines in 1928 that definitely eliminated the theoretical 5-foot control and caused the inter-changing, earlier discussed, of the relative positions of the 4- and 5-foot controls in 1930.

The inlet.—The inlet for the water supply was through a line of 4-inch tile entering the 5-inch control line at the northwest corner of the tract.

Control weirs.—Control of the water levels was effected by means of the weirs, the locations of which are shown in Figure 2. The weir boxes, the plans for which are shown in Figure 3, were made of good quality ¾-inch dressed and matched white pine reinforced by 2x4-inch collars. The weir aprons were of a similar material to the box wall. They were removed each fall to lower the water level before freeze-up and were replaced each spring.

Test wells.—Lines of test wells in which to measure the actual height of the ground-water table were located as shown on the plan in Figure 2, except that, for 1925, in place of the C_e and C_w lines there was only one C line right over the main tile. These test wells were of 4- or 5-inch drain tile and extended to depths of 5 to 7 feet below the surface. The tops of the wells were approximately at the bog surface and each was capped with a wooden cover, painted white with the well number in black, held in position by a small block extending down into the well several inches. Each series of wells began with number 1 at the north end, the numbers running through, consecutively, to the south end except on the B and D lines where additional wells set, on each control, 5 feet in from the marginal wells, were in each case given the marginal well number followed by an "a." That is, for example, the numbers ran 1, 1a, 2, 3a, and 3 across the 1-foot control, 4 in the center of the transition plot, 5, 5a, 6, 7a, and 7 across the 2-foot control and so on to the end of the series.

Experience during the season of 1925 seemed plainly to indicate that the sand subsoil under the northeast corner robbed the water from the

5-inch tile loops on the 1- and 2-foot controls to such an extent as to make it impossible to maintain the desired elevation of the groundwater table on these plots east of the main. Hence, at the beginning of 1926, in the hope of offsetting the influence of the sand deposit, the old loops of tile on the east half of these 2 controls were plugged and new loops were laid from 2 to 2½ feet deep but not tapping the sand deposit. As the original surface at the extreme northeast corner was noticeably higher than the rest of the bog and as there were some extra low spots at the north end of the west half, some leveling down of the surface also was done in the spring of 1926 in the hope of further offsetting the influence of the sand subsoil. Very little was accomplished by these modifications, the sand deposit seeming to be of too great a depth or too dry for its influence to be overcome.

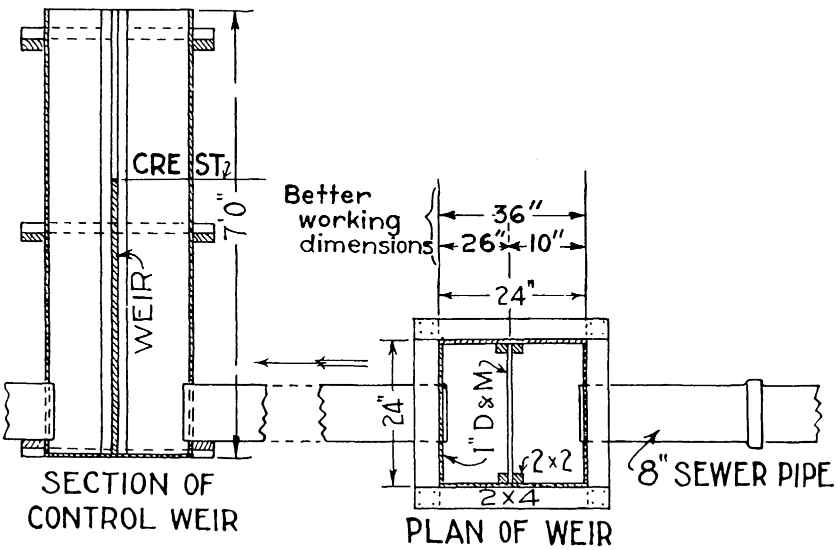

FIG. 3. PLAN OF CONTROL WEIR BOXES

SURFACE AND SETTLING OF THE BOG

The original surface of the bog after clearing was moderately smooth, with a fairly uniform fall toward the south as indicated on the profile in Figure 2. However, bearing out almost universal experience and observation on reclaimed and cultivated peat bogs, the surface of the bog settled measurably after the installation of the tiling system in 1921. The levels taken each summer season from 1925 to 1928, inclusive, indicated that the subsidence of the surface due to the influence of the tile lines in their original position was completed before 1925, but, as will be seen clearly in Figure 2, this settlement was sufficient to destroy

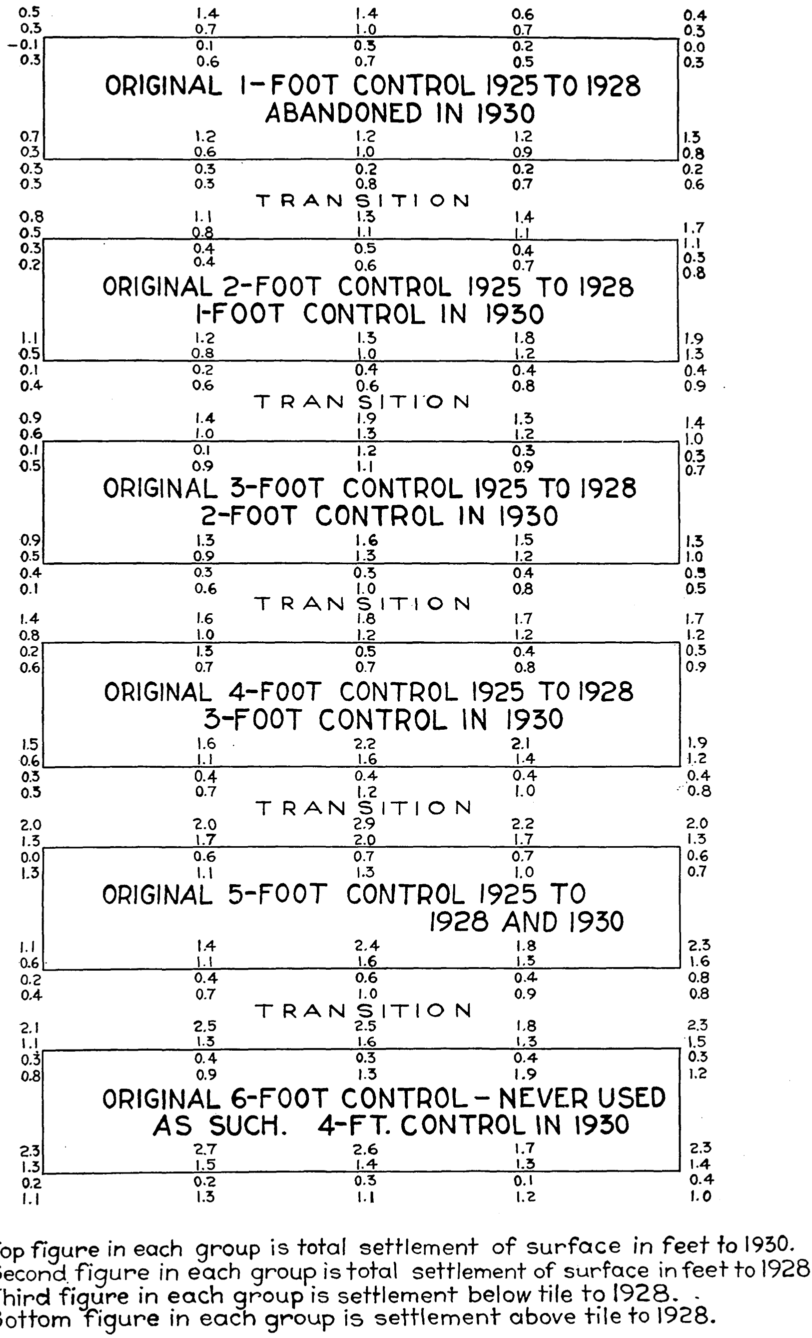

FIG. 4. DIAGRAM OF THE EXPERIMENTAL TRACT SHOWING SETTLEMENT OF THE SURFACE FROM DRAINAGE AND TILLAGE

the possibility of obtaining a 6-foot depth of water table and even to interfere with the 4- and 5-foot controls to a serious extent. While the deepening of the tile lines in 1928 was partially successful in overcoming this difficulty on the 4- and 5-foot controls, it also, without question, disturbed the apparently completed condition of surface subsidence with the result that an additional settlement was brought about.

The amount of settlement is given in Figure 4 in which the top number in each vertical column of 4 indicates the total surface settlement to 1930, the second number the total settlement to August 1928, the third number the total settlement below the tile to August 1928, and the lowest number the settlement above the tile to the same date. This last is evidently the most significant and varies from an average of about 0.5 foot at the north end to about 1.1 feet at the south end of the tract up to August, 1928, the variation being approximately proportional to the depth of the water table, as might be expected.

Data on the settlement below the tile concurrent with the later settlement of the surface are not available but it seems reasonable to assume that the part of that settlement below the tile bears about the same ratio to the total settlement as it did in the period previous to August, 1928.

THE WATER LEVELS

Method of measurement.—The height of the top of each test well above the surface of the bog was measured each season. The depth of water table below the top of each well was measured every Monday and Thursday throughout each season. The depth of water table below the surface at each well was then obtained by subtracting the height of the top of the well above the bog surface from the depth of the water below the top of the well.

It was expected that there would be some arching upward of the water table across the plots between the tile lines, as is the case in any ordinary tile drainage system, but this was not generally the case on the experimental tract as subsoil conditions and water demands of crops held the water table nearly flat or even depressed in some instances. In view of this latter fact, in this study it has been found that an average of the contemporary readings on any set of 3 wells, as, for example, 5, 6, and 7 on the "B" line was just as accurate for determining the depth of water table under any given strip of crop as was the average of the 5 wells, 5, 5a, 6, 7a, and 7, the two averages often being the same within one-tenth of a foot and never varying from each other in excess of three-tenths of a foot. Hence the 3-well average was used throughout for all plot cross-sections. Differences in averages between 2 cross-sections were prorated for any given season to obtain the approximate average depth of water table under any crop strip hereinafter discussed.

Reliability of method of control of ground-water level.—In the same manner as above described, general averages of quarter plots and of half plots were obtained for purposes of comparing the depths of water table on any given plot or portion thereof for 2 or more successive seasons. This was done because the question has frequently been raised of the possibility and practicability of controlling the depth of water table by such a system as was used on this tract. The experience here indicates clearly that such control within practical limits is possible. Its economic feasibility will always depend on local conditions of water supply, crops to be raised, and availability of markets. Table 3 supports our claim of the possibility of control.

Table 3.—Average Depths of Water Table below Surface, in Feet, on the Water-Controlled Peat Plots, for Each Year 1925 to 1928 and 1930, with Grand Average for the Five Years in Comparison with 1929

Control zone	West half: Average depth for— 1925	1926	1927	1928	1930	5 years	1929
1-foot	1.2	1.0	0.9	0.9	1.0	1.0	2.9
2-foot	2.4	2.0	2.0	1.9	1.9	2.0	2.9
3-foot	3.3	3.0	3.0	3.0	3.4	3.1	2.9
4-foot	4.1	3.8	3.8	3.9	4.7	4.0	3.1
5-foot*	4.6	4.4	4.2	4.2	5.2	4.5	3.1

Control zone	East half: Average depth for— 1925	1926	1927	1928	1930	5 years	1929
1-foot	1.8	1.6	1.3	1.4	1.3	1.5	3.6
2-foot	2.3	2.1	2.0	2.0	2.0	2.1	3.2
3-foot	3.1	2.9	2.9	2.8	3.0	2.9	2.9
4-foot	4.0	3.7	3.7	3.8	4.4	3.9	2.8
5-foot*	4.3	3.9	3.7	3.8	4.8	4.1	2.8

Control zone	Total plot: Average depth for— 1925	1926	1927	1928	1930	5 years	1929
1-foot	1.5	1.3	1.1	1.1	1.1	1.2	3.2
2-foot	2.4	2.0	2.0	2.0	2.0	2.0	3.0
3-foot	3.2	3.0	3.0	2.9	3.2	3.0	2.9
4-foot	4.0	3.8	3.8	3.9	4.5	4.0	3.0
5-foot*	4.5	4.2	4.0	4.0	5.0	4.3	3.0

* The marl subsoil prevented the lowering of the water table to full 5 feet.

Maximum and minimum heights.—Figure 5 shows, diagrammatically, for all seasons except 1929, the approximate maximum, minimum, and average elevations of the water table, along the B and D series of wells. Figure 6 shows similar data for the season of 1929 during which it was endeavored to keep the water table at a uniform depth of 3 feet over the entire tract. The upper and lower curves representing the maximum and minimum elevation of the water table for the period are discontinuous as to dates and hence purely diagrammatic. On the other hand, the average curve in each figure is the exact average of the 4 months June to September, inclusive, for the 5-year period or for the entire season of 1929, according to which set is being considered.

Pertinent facts relative to the water control.—The following interesting and pertinent facts become evident from a study of the charts in Figures 5 and 6 in conjunction with Table 3 and the rainfall record for each season from May to October, inclusive, shown in Figures 7 and 8, and Table 4, showing the mean monthly precipitation at the bog throughout the period of tests, together with the official normal from the Chaska record.

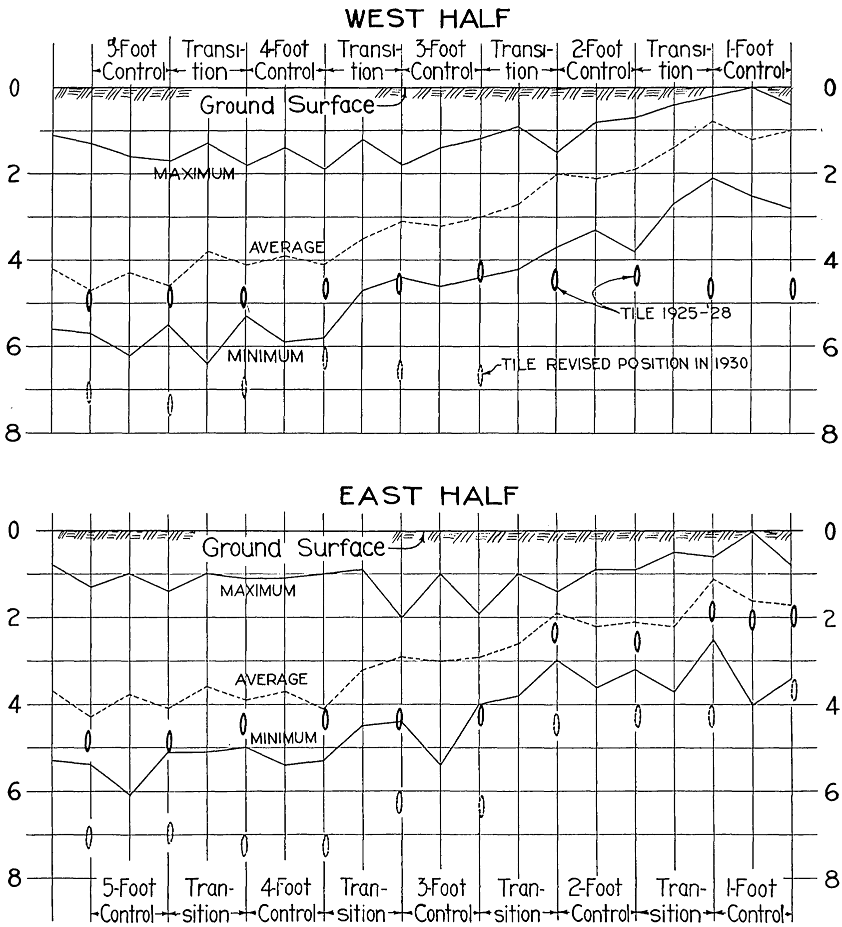

Fig. 5. Maximum, Average, and Minimum Heights of Water Table Along the D Line (West Half) and the B Line (East Half) for all Years Except 1929

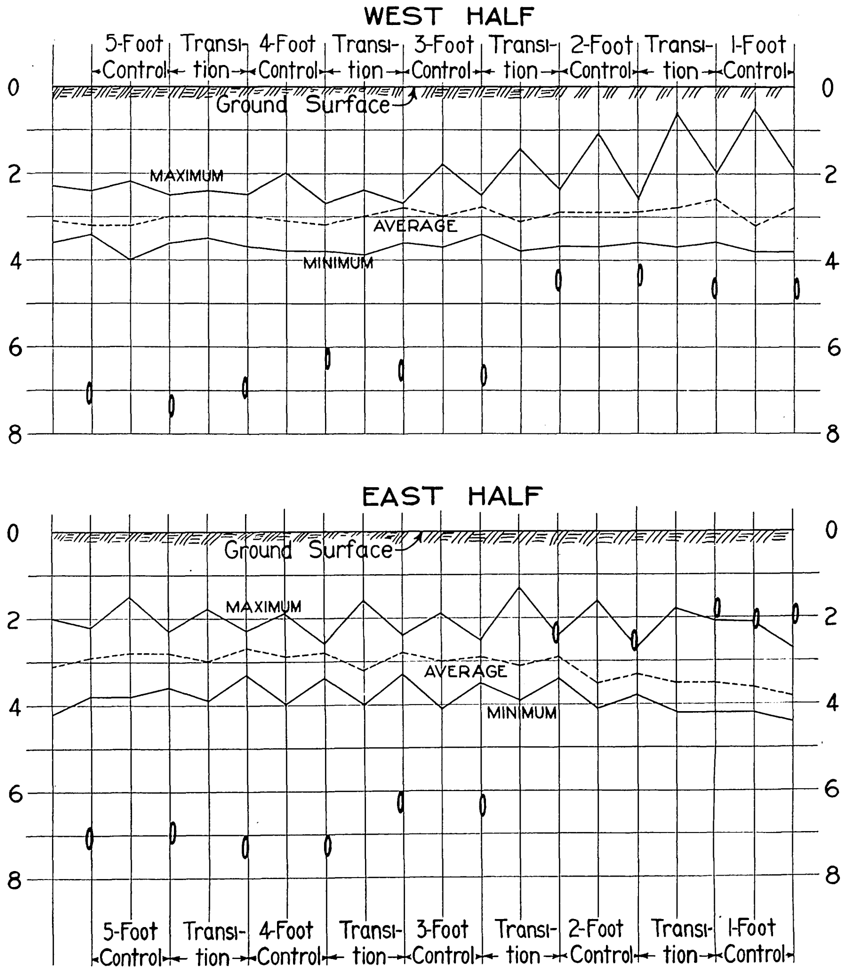

FIG. 6. MAXIMUM, AVERAGE, AND MINIMUM HEIGHTS OF WATER TABLE ALONG THE D LINE (WEST HALF) AND THE B LINE (EAST HALF) FOR 1929 ONLY

1. The average height of the peak of the ground-water surface will sometimes exceed that over the tile lines by from 0.25 foot to a foot, according to frequency and amount of rainfall and to moisture demands of crops; while the variation, at the peak of the ground-water curve, between maximum and minimum heights will have a range of from 1 to 3 feet, from the same causes.

2. Subsoil conditions, the physical character of the deeper layers of the peat, the type of crop, its normal rooting depth, its moisture requirements, and the time, amount, and character of the rainfall all tend to militate against the exact maintenance of any particular average depth of water table that may theoretically be provided for.

3. Maximum heights of the ground-water table tend to occur from the day of the rain up to 3 to 5 days after heavy precipitation, according to the month and the moisture demands of crops.

4. Exact control of the height of the water table is impossible without greatly decreasing the spacing between the control lines of tile, and such a proceeding would make the cost of the plant prohibitive in practice except in the rare cases of types of crop of unusually high return, in the neighborhood of a good and steady market. However, the degree of control attained seems clearly demonstrated as possible where the peat is deep (4 feet or more), the subsoil not unusually porous, and the water supply ample. It further appears as sufficiently steady to be practical in case of most of the standard crops raised throughout the tests.

Table 4.—Monthly Precipitation at Peat Plots, 1925-1930

Month	1925	1926	1927	1928	1929	1930	Normal*
January	....	1.13	0.53*	0.59	1.78	1.25	0.82
February	....	0.58	0.43*	1.65	1.25	2.05	0.66
March	....	1.30	2.40*	1.45	1.52	0.10	1.30
April	....	0.64	2.68*	4.60	1.20	0.77	1.63
May	2.39*	1.26	4.21	2.43	2.58	3.74	2.90
June	8.95*	4.40	4.69	3.83	4.70	5.31	4.18
July	5.87	4.91	3.04	4.39	5.09	1.97	3.10
August	0.48	4.89	2.73	5.41	2.00	1.28	2.89
September	5.12	5.74	4.19	2.04	3.91	4.19	3.85
October	0.46	2.30	2.58	4.20	2.51	0.95*	2.07
November	0.53	1.64	1.59	0.19*	0.36	2.01*	1.37
December	0.85	1.11	2.15*	0.60	0.50	0.07*	0.82

* For Chaska, Minnesota, 10 miles southwest of the peat plots.

PREPARATION OF THE SEEDBED

The entire tract, with the exception of the grass-crop section, was ploughed each spring, disked, harrowed, and the surface finally packed by rolling with a heavy concrete roller. It is necessary, for best results, thus to pack the surface of peat land in order to render the surface firm and to enable the compacting of the soil around the seed, so necessary to obtain good germination.

THE GENERAL CROPPING SCHEME

The rows of each crop were run north and south the entire length of the tract, thus crossing all plots. Crops were replicated in all cases where available space permitted. However, the replication of truck crops was not possible in all cases the first three years because a portion of the tract was then used in another line of work.

FERTILIZATION

For 1925 and 1926 the furnishing and distribution of fertilizer was handled by the Division of Agronomy. In the spring of 1925 a uniform application of muriate of potash at the rate of 400 pounds per acre and 45 per cent triple superphosphate at the rate of 200 pounds per acre

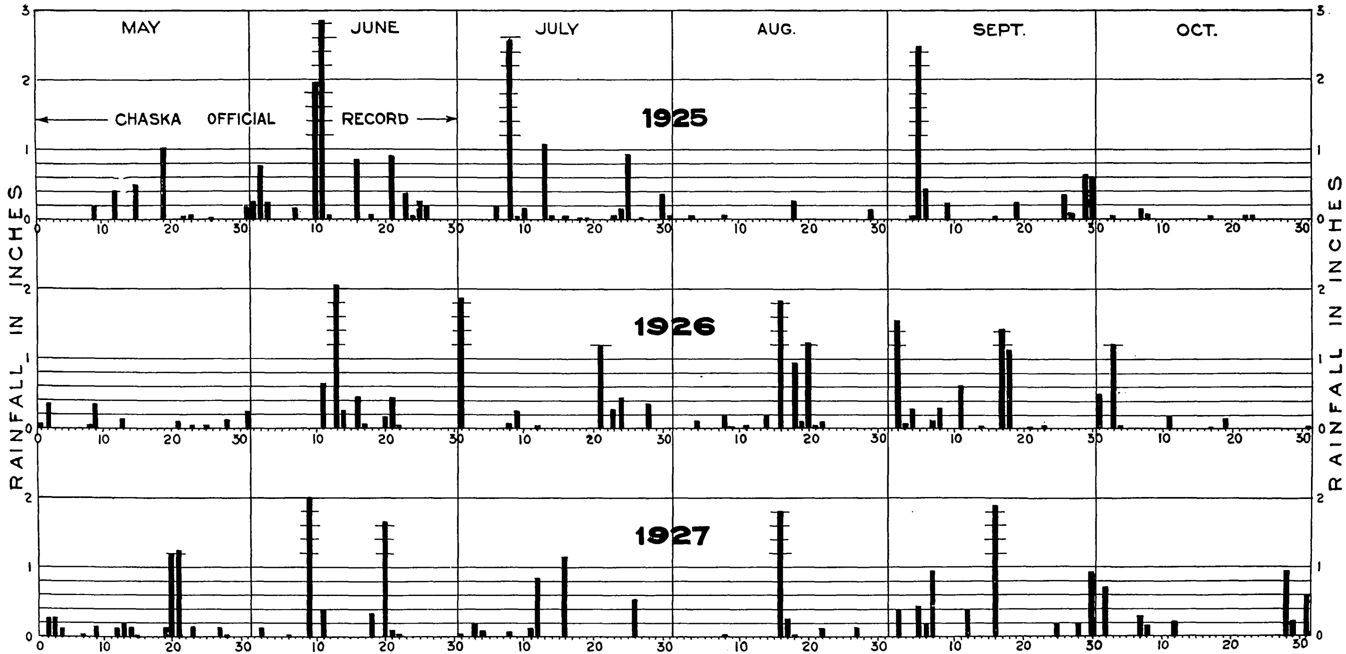

FIG. 7. RAINFALL RECORD AT THE WATER-CONTROLLED PEAT PLOTS FROM MAY TO OCTOBER, INCLUSIVE, EACH YEAR FROM 1925 TO 1927, INCLUSIVE

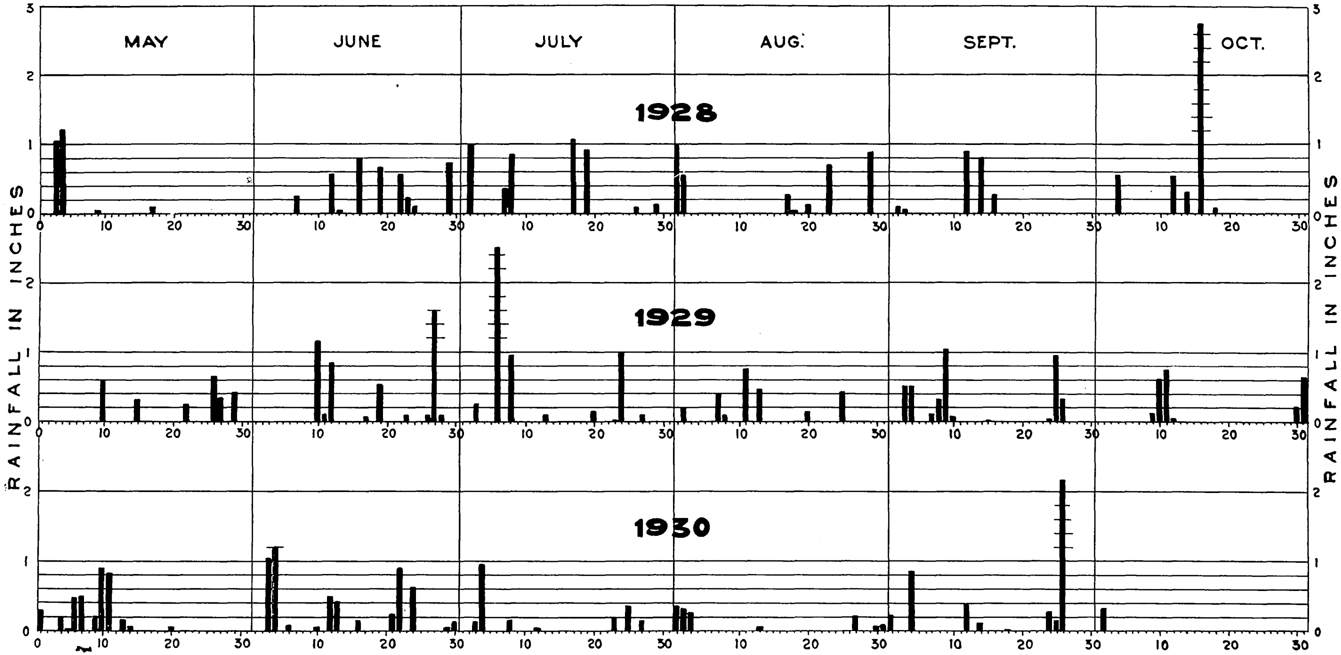

FIG. 8. RAINFALL RECORD AT THE WATER-CONTROLLED PEAT PLOTS FROM MAY TO OCTOBER, INCLUSIVE, EACH YEAR FROM 1928 TO 1930, INCLUSIVE

was made over the entire tract. After that during the 6-year period of the tests no more fertilizer was applied to the field crops. The truck crops, however, were supplied each year, by the Horticultural Division, with muriate of potash at the rate of 400 pounds per acre and with 16 per cent superphosphate at the rate of 600 pounds per acre.

CROPS RAISED

Field crops.—The field and forage crops raised in connection with these tests were as follows: sugar beets, field corn, flax, oats, soybean hay, and timothy and clover hay.

Truck crops.—The truck crops raised in connection with these tests were as follows: beans, sweet corn, onions, potatoes, carrots, summer radish, winter radish, cabbage, cauliflower, spinach, lettuce, tomatoes, and celery.

CROP YIELDS AND QUALITY

The yields were determined for each crop on each theoretical control plot by the Division of Agronomy and Plant Genetics for the field crops and by the Division of Horticulture for the truck crops. These yields were then regrouped by the Division of Agricultural Engineering according to the actual depth of water table under the various parts of each crop strip, as definitely determined from the measurements taken twice a week throughout the season. The comparative yields thus obtained are shown for each half foot difference in ground-water level for each crop, with general notations, in Tables 5 to 22, inclusive, except for flax, cauliflower, and head lettuce which could not be thus shown because exact figures for yields were lacking. In these tables averages are shown only where yields from 3 to 5 years are available for any given depth of water table as averages for only 2 years would have no significance and in many cases even 3-year averages may be questionable. In order readily to permit the comparison discussed under "Theoretical depths of water table," page 9, available yields for 1929 are shown separately and are not included in the averages.

Table 5.—Sugar Beet Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1925	....	10.9	15.4	21.0	20.8	21.6	21.2	18.4	....	....
1926	....	14.6	12.3	15.1	13.8	16.3	14.0	19.2	....	....
1927	....	8.2	....	9.2	6.1	9.1	9.3	10.6	....	....
1928	12.5	....	8.5	3.4	1.9	4.5	7.0	8.2	....	....
Average	....	11.2	12.1	12.2	10.7	12.9	12.9	14.1	....	....

Sugar beets.—Depth of water table seems to have had no marked influence on size of yield. On the 1- and 2-foot controls there was a marked tendency to hollowness and rot. The best quality product was always on the deeper controls (3 to 4.5 feet). Reduced yields after 1926 seem unquestionably due to lack of fertilizer.

The general appearance of the 1929 crop, which was wholly neglected after planting, indicated that with proper care it would have been good.

The 1930 crop was harvested in error before yields were taken. Its general appearance indicated the best crop in the 6 years, altho it received very little attention after planting. On the east half the crop was small and immature but on the west half it was fine looking.

Table 6.—Field Corn Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Bushels of 70 pounds ear corn									
1925	....	52.5	59.1	74.3	77.3	84.1	78.4	71.9	58.4	....
1926	58.8	57.0	....	72.6	74.4	55.5	57.1	57.0	....	....
1927	....	11.1	11.4	22.6	27.0	17.7	....	....	....	....
1928	....	....	9.8	28.9	27.8	39.8	16.1	26.3	....	....
1930	....	36.9	....	52.8	....	25.8	41.1	33.4	25.1	43.8
Average	....	39.4	26.8	50.2	51.6	44.6	48.2	47.2	....	....

Field corn (grain).—The marked trend for best yield and quality was with moderately deep drainage (2½ to 5 feet). The greatly reduced yields after 1926 were probably owing to lack of fertilizer.

In 1925 absence of summer frost damage combined with good care resulted in early maturing. In 1926, 1927, and 1928 June frosts caused serious injury and replanting on all below the 2-foot control. This occurrence, combined with mid-September frosts, prevented full maturing of ears in 1926 and 1927, but in 1928 favorable weather through July and August resulted in full maturing of the crop. In 1929 frost conditions similar to those in 1927, a cold wet season, and utter lack of care of the growing crop resulted in no mature grain. In 1930 favorable weather conditions resulted in early maturing and a good crop with little care after planting. Liability to summer frost is evidently the great natural hindrance to good results with field corn on peat land.

The variety used throughout was Minnesota Number 13.

Table 7.—Field Corn Stover Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1925	....	1.8	1.7	2.5	2.7	2.9	2.7	2.7	2.5	....
1926	2.1	2.0	....	2.5	2.7	2.2	2.1	2.0	....	....
1927	....	1.1	0.6	1.6	1.0	1.5	....	....	....	....
1928	....	....	1.1	3.7	4.9	6.0	4.5	6.8	....	....
1930	....	2.8	....	5.5	....	3.8	2.6	4.2	2.6	3.8
Average	....	1.9	1.1	3.2	2.8	3.3	3.0	3.9	....	....
1929	....	....	....	....	2.9	....	....	....	....	....

Field corn stover.—The same general comments as those given under "Field corn (grain)" are applicable here.

Flax.—For the season of 1925 good yields in both grain and straw quite comparable with satisfactory yields of flax on mineral soils were obtained, these yields varying between 6 and 9.8 bushels of grain and between 1.5 and 1.8 tons of straw per acre. The best yields were definitely on those parts of the tract where the ground-water level was in the actual 3.0- to 3.5-foot zone, where yields varied from 8.6 to 9.8 bushels of grain and from 1.7 to 1.8 tons of straw. In several other cases the straw was equally good but the grain yield in these other cases was less than 7 bushels per acre. The varieties planted were North Dakota 114 in 1925 and 1926 and Winona the other years.

In the 4 following seasons on all controls the flax was so choked by weeds as to be valueless; hence, it was not included in the 1930 scheme. Whitson and Ulsperger (9) state that altho flax is recommended as a good first crop on peat, yet it cannot be recommended as a permanent crop for marsh soils because of its small root system and its inability to secure plant food elements. Alway states that, in general, on Minnesota peat soils flax is a good first crop on any breaking but after the first year it is apt to be unsatisfactory because of weeds. Arny (3, 6), however, adds that if the weed nuisance can be overcome, flax is a good peat land crop any year if not seriously injured by frost.

Table 8.—Oat Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Bushels of 32 pounds of grain									
1925	....	18.0	....	21.9	20.7	21.3	17.1	16.1	16.1	....
1926	....	15.6	10.0	18.6	....	20.3	14.0	13.7	11.7	....
1927	....	12.6	....	7.0	5.5	4.6	1.4	6.5	....	....
1928	23.1	....	11.6	19.9	2.7	15.8	41.0	29.5	....	....
1930	27.1	43.8	28.7	18.7	....	....	27.2	....	26.0	16.1
Average	....	22.5	16.8	17.2	9.6	15.5	20.1	16.5	17.9	....

Oats (grain).—Depth of water table seemed not to have been a marked factor in size of yield, which was not good any year of these tests. This is not readily accounted for as, according to Alway (1, 2) and Arny (3, 6), oats has usually proved a good peat land crop in Minnesota except where it has lodged or rusted severely, these being the two great handicaps with oats on peat. There was no definite evidence of damage from summer frosts, but weeds seemed to tend to crowd out the oats which ran largely to straw. There was no visible evidence of why the 1930 crop was the best of the six. Figures shown for 1928 were measured bushels which ran about 33 per cent low in weight. Straw for that year was estimated.

Gopher was raised all years but 1927, when Minota was sowed.

Oat straw.—The yield of oat straw seemed little affected by depth of drainage. A fair yield was obtained on all controls practically throughout the period of tests.

Table 9.—Oat Straw Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1925	......	1.9	1.9	2.2	2.0	2.2	2.1	1.9	1.9	......
1926	......	2.1	......	2.0	......	1.9	2.1	2.0	2.3	......
1927	......	1.6	......	2.1	1.7	2.9	2.4	3.1	......	......
1928	......	......	1.3	1.9	1.8	1.9	1.9	2.0	......	......
1930	2.0	2.7	2.4	2.7	......	......	2.6	......	......	3.0
Average	......	2.1	1.9	2.2	1.8	2.2	2.2	2.3	......	......

Table 10.—Soybean Hay Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1926	......	2.9	3.1	2.6	......	2.1	1.4	2.8	......	......
1927	......	3.1	......	2.2	2.0	1.2	1.0	1.1	......	......
1928	1.2	......	1.8	......	......	2.0	1.5	......	......	......
Average	......	......	......	......	......	2.7	1.3	......	......	......

Soybean hay.—The marked reduction in yields after 1926 may be due to lack of fertilizer. With proper fertilization and care, soybeans for hay have usually been found well suited to peat soil, altho in these tests the experience indicated that summer frosts may be considered as a serious disadvantage. Each season on the 3- to 5-foot controls, June frosts caused noticeable injury to the young plants, killing some and making some replanting necessary, while in 1926 and 1927 August and early September frosts prevented maturing of seed. On account of the greater severity of frosts on the deeper controls, the yields usually decreased with the depth of the water table below 1.5 feet.

The variety grown was Chestnut.

Table 11.—Timothy and Clover Hay Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1927	5.1	4.2	6.3	5.0	5.0	5.4	5.3	......	......	......
1928	2.4	2.1	3.7	2.7	2.3	2.8	2.7	......	......	......
1930	4.6	3.6	4.3	3.8	3.4	4.5	3.7	3.5	3.7	......
Average	4.0	3.3	4.8	3.8	3.9	4.2	3.9	......	......	......
1929	......	......	......	......	3.7	......	......	......	......	......

Timothy and clover hay.—It is evident that neither summer frosts nor depth of drainage below the one-foot level was a governing factor in yields.

The noticeably higher yield in 1927 was probably due to the predominance of clover. The marked decrease in yield in 1928 was probably due to the decadence of the clover without as marked a strengthening of the timothy stand, whereas the uniformity and size of yield in 1930 was probably owing to the matured development of the timothy.

It has been the common experience that, even with only a small amount of reliable drainage, peat land is good for grass crops.

Table 12.—Snap Bean Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1926	......	......	1.2	......	1.4	......	......	1.1	......	......
1928	......	1.9	2.2	......	3.8	......	......	4.2	......	......
1930	......	7.7	......	7.9	......	3.4	2.2	......	5.7	......
1929	......	......	......	......	3.6	......	......	......	......	......

Snap beans.—For a considerable range of moderate drainage—1.5 to 4.0 feet deep—it appears evident from these tests that extra heavy yields of beans are possible on peat when summer frosts are lacking. However, the latter are a serious obstacle to success with beans.

In 1925 no frost damage was experienced and the resulting crop was good in both size and quality with the water table 1.5 feet or more deep, but no exact record of the yield was obtained. In 1926, June frosts caused no serious damage on the 1- and 2-foot controls but made necessary much replanting on the deeper controls. In 1927, June frosts, followed by early August and September frosts, resulted in no crop of significance even after extensive replanting late in June. In 1928, 1929, and 1930, June, August, and early September frosts noticeably reduced the crop on the controls below 2 feet.

Varieties raised were Bountiful, 1925 to 1928, inclusive; Sutter's Greenpod in 1929, and Stringless Greenpod in 1930.

Table 13.—Sweet Corn Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1925	......	......	2.7	3.7	......	3.6	3.5	......	3.3	......
1926	......	......	1.7	3.0	3.4	......	2.7	2.5	......	......
1927	......	1.4	3.6	......	5.0	......	3.4	......	......	......
1928	......	1.3	2.8	......	3.2	......	2.8	3.3	......	......
1930	......	1.3	2.0	......	......	2.8	......	......	0.8	2.3
Average	......	1.3	2.6	......	3.9	......	3.6	......	......	......
1929	......	......	......	......	2.7	......	......	......	......	......

Sweet corn.—Depths of water table from 2 to 4.5 feet seemed to produce best results with sweet corn both in quality and yield with uniformity of care and fertilization throughout.

While June frosts and floods in 1926 and June frosts in 1928 and 1929 resulted in considerable replanting, they seemed to cause no serious loss of crop. Hence, while sweet corn is quite susceptible to frost, the yield does not seem to be affected by early summer frosts unless they come while the corn is in the silk or just before or after, as the season is long enough in our latitude to allow replanting and maturing before the late summer and early fall frosts occur.

Golden Bantam was raised all years except 1929 and 1930 when Sunshine was raised.

Table 14.—Onion Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Bushels of 52 pounds									
1925	....	....	....	809	....	832	1,014	1,107	....	....
1928	....	....	259	317	463	231	....	....	....	....
1930	....	721	....	1,218	....	1,427	....	1,231	1,201	....
Average	....	....	....	781	....	830	....	....	....	....

Onions.—Onion yields secured compare favorably with those obtained by other investigators with peat soils. An excellent and abundant crop can be grown with moderately deep drainage—3.5 to 4.0 feet. Both shallower and deeper drainage seem usually to result in many scullions and poor development.

In 1926, 1927, and 1929, with the same care as other years, there was no visible evidence to account for the general trend to scullions with few and unmarketable bulbs in any case. In 1927, washing from heavy rains early in June resulted in extensive replanting. The effects of summer frosts seem negligible in onion culture on peat.

Currence (4), co-operator from the horticultural group, from his observations and data from the same set of tests for the 3 years of 1925, 1928, and 1930, the only years of the 6 when the crop matured, is inclined to conclude that there was a greater tendency to scullion development when the depth of the water table was much over 3 feet. Currence further observes that maturity seemed earlier with shallow drainage and thinks this may be due to restriction of plant development resulting from scarcity of nitrogen in the wetter soil. His analysis of quality indicates that the greatest percentage of marketable onions was usually obtained at the 3-foot level.

White Globe was raised in 1925, 1926, and 1930; Ebenezer the other 3 years.

Table 15.—Potato Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Bushels of 60 pounds									
1926	....	....	265	....	214	....	155	125	....	....
1927	....	70	....	296	344	....	412	....	....	....
1928	....	226	326	....	422	....	400	....	....	....
1930	115	140	240	....	....	192	....	....	128	152
Average	....	145	277	....	327	....	322	....	....	....
1929	....	....	....	....	324	....	....	....	....	....

Potatoes.—Yields obtained indicate that moderate depths of drainage—from 2 to 3½ feet—are essential for good results with potatoes. With shallower drainage the tubers tended to be small, rough, and watery. With deeper drainage they tended to be few and very small. These general conclusions are well supported by the results obtained in 1929 when the yield obtained was remarkably uniform and of good quality, with the water table held at a uniform depth of 3 feet over the entire tract.

Early summer frosts prove a great hindrance to development if not actually fatal. Midsummer frosts are always disastrous. Late summer frosts are a menace to later varieties even when they escape serious frost damage in the earlier part of the season. These conclusions are well supported by the yields from 1926 to 1930, inclusive, most uniform results being obtained in 1929 when little frost damage occurred. Low yields in 1930 may, in part, be accounted for probably by a long period of relatively cool weather in July.

Triumphs were raised in 1925 with excellent and uniform results—256 to 346 bushels per acre—below the 1.5-foot level, but these figures are not shown in the table because they could not be consistently averaged in with the yields from the Cobblers which were raised all the other years.

Table 16.—Carrot Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1926	....	....	9.4	13.9	15.5	....	11.2	....	....	....
1927	2.1	....	6.3	....	5.5	5.2	7.1	....	....	....
1928	....	....	21.0	17.9	17.2	11.8	14.7	....	....	....
1930	....	13.4	17.3	....	....	8.1	....	4.7	2.6	10.2
Average	....	....	13.5	....	12.7	8.4	11.0	....	....	....
1929	....	....	....	....	7.4	....	....	....	....	....

Carrots.—Drainage deeper than 5 feet and shallower than 2 feet gave small roots, and on the shallower levels they were badly branched. Yield and quality were good in almost all cases for depth of water table between 2 and 5 feet. The 1925 crop was good in appearance and quality, but no yield record was secured. There was no evident cause for the small yield in 1929.

Summer frosts did not seem to affect the carrots in any way.

Chantenay was raised 1925 to 1928, inclusive; Nantes in 1929 and 1930.

Table 17.—Summer Radish Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1926	......	......	11.9	11.5	12.4	......	13.5	11.2	......	......
1928	......	14.5	19.6	......	20.7	......	14.3	12.4	......	......
1930	......	......	11.0	11.5	9.2	7.4	......	5.8	7.0	......
Average	......	......	14.2	......	14.1	......	......	9.8	......	......
1929	......	......	......	......	5.9	......	......	......	......	......

Summer radish.—The 1925 crop, for which no figures on yield were secured, gave a uniformly large product of good quality with depths of water table from 2.5 to 4.5 feet. Those on the higher controls were rough and of poor quality. The 1927 crop was a failure unaccounted for unless by the relatively cold, wet season. Results in 1926, 1928, and 1930 showed that good results in both quality and yield are obtainable with depths of water table from 2.5 to 5 feet, but that with shallower drainage a rough and tasteless or bitter yield usually results. There was no evident explanation of the small yield in 1929.

Summer frosts did not appear to be a factor in growing radish on peat.

The variety used throughout was Scarlet Globe.

Table 18.—Winter Radish Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1926	......	......	14.5	20.0	29.0	......	29.1	......	......	......
1928	......	7.1	31.6	......	13.1	......	......	15.8	......	......
1930	......	12.2	11.7	......	......	6.5	......	8.4	......	10.9
Average	......	......	19.3	......	......	......	......	......	......	......
1929	......	......	......	......	15.7	......	......	......	......	......

Winter radish.—Winter radishes were not planted in 1925 and 1927. The relatively poor yields in 1930 were from no evident cause. In the main the results, both in yield and quality, other years indicated that good results may be obtained with almost any depth of water table of 2 feet or more. On the higher controls the quality was poor.

Summer frosts seemed not to be a factor of importance with winter radish.

Japanese Winter was raised in 1928 and China Rose the other two years.

Table 19.—Cabbage Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1925	....	....	....	21.2	....	19.5	18.7	18.3	....	....
1926	....	....	13.8	15.2	14.8	....	14.0	....	....	....
1927	....	4.6	15.6	....	15.1	....	13.9	12.6	....	....
1928	....	6.1	14.2	....	14.9	....	13.0	....	....	....
1930	....	11.6	12.3	....	....	10.2	....	....	8.6	9.5
Average	....	7.4	14.0	....	14.9	....	14.9	....	....	....
1929	....	....	....	....	12.8	....	....	....	....	....

Cabbage.—Good results in both yield and quality were obtained at almost any depth of water table with a tendency for best results with depth of 2 to 4 feet. Summer frosts were not a factor to be reckoned with.

Cabbage is one of the most productive crops on peat.

Cauliflower.—This crop was included in the cropping scheme only in 1925, 1927, and 1930. Yields were not reported in definite terms of measure or weight but only in terms of general quality and extent of development. A best quality crop was secured quite generally on all areas where the depth of water table was from 1.0 to 3.0 feet, with a tendency for best results over the higher levels. Above and below these limits the crop was not generally either vigorous or satisfactory. Varieties raised were the Early Snowball in 1925 and 1927 and Ford's Catskill Snowball in 1930.

Head lettuce.—Head lettuce was included in the cropping scheme only in 1926 to 1928 and 1930. Only in 1927 were any satisfactory results and any heads obtained. These were on the areas where the depth of the ground water varied from 2.5 to 5.0 feet. On all other controls and in all other seasons no marketable product was obtained. General observations indicated that this failure was due to the intense heat occurring during the summer days on bogs in this latitude.

Table 20.—Spinach Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1927	....	0.8	1.8	....	2.9	....	3.4	....	3.9	....
1930	....	....	0.2	0.7	1.5	0.9	....	0.4	1.1	....
1929	....	....	....	....	3.9	....	....	....	....	....

Spinach.—Yields on the different controls in the different years were so contradictory and inconclusive as to eliminate any special mention. Of this result there is no evident explanation as spinach has usually proved a good peat land crop among growers.

Varieties raised were King of Denmark in 1927 and 1930 and Long Standing in 1929.

Table 21.—Tomato Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds, of ripe fruit									
1926	....	....	....	13.4	15.2	....	11.3	12.5	....	....
1927	....	2.2	12.1	....	15.2	4.5	....	....	....	....
1928	....	17.7	19.8	....	14.7	....	....	10.5	....	....
1930	....	14.0	16.4	....	....	11.0	....	10.9	12.7	....
Average	....	11.3	16.1	....	15.0	....	....	11.3	....	....
1929	....	....	....	....	20.1	....	....	....	....	....

Tomatoes.—While tomatoes seemed to do well for any depth of water table of 2 feet or greater, the optimum range seemed to be from 2 to 3 feet. On the shallower controls the vines tended to unhealthy, soft growth and the fruit was small and mostly of poor quality. June frosts were disastrous, as a rule entirely killing the young plants. This was especially true in 1927 and accounts for the low and uneven yield that year. In 1930 there was no frost damage until late fall with the result of a good and uniform yield. Midsummer and late summer frosts injured the top and outer parts of the plants, but the lower parts, being protected by the dense upper growth, usually recovered after several succeeding days of mild weather and the fruit largely escaped harm and matured. The 1929 crop showed unusually vigorous resistance to early fall frosts.

Oshkosh Earliest was raised in 1926, John Baer in 1927, Stone in 1928, and Red River in 1929 and 1930.

Table 22.—Celery Yields Per Acre

	Depth of water table in feet									
	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0	5.0 to 5.5
Year	Tons of 2,000 pounds									
1928	....	....	23.7	29.7	36.6	....	32.3	....	....	....
1930	....	36.3	29.3	....	....	20.3	....	......	22.2	25.9
1929	....	....	....	....	25.5	....	....	....	....	....

Celery.—No definite figures on yields were supplied in 1925, 1926, or 1927, but a good quality product was reported for depths of water table from 1.5 to 4.5 feet, the finest development being at the medium depths. Where the depth of water table was appreciably less than 1.5 feet, the plants did not develop.

Summer frost damage was negligible except in cases of very sharp early frosts when the plants were freshly set and still very small.

It is the general experience that celery is well suited to peat land.

Varieties raised were as follows: Golden Self Blanching in 1925 and 1930, Golden Crisp in 1926, Golden Plume in 1927 and 1928, and all three of these varieties in 1929.

RECOMMENDATIONS FOR DEPTH OF DRAINAGE IN PEAT

A thoro study of the results of the tests herein discussed does not show any marked difference between the average optimum depth of drainage for field crops and that for truck crops. Frequently either or both will be raised from time to time on the same field. Usually it will not be feasible or profitable to attempt an elaborate ground-water control system that will permit maintaining the ground-water level at different depths on different fields or portions thereof on the same bog. Hence it is recommended that an approximately uniform average depth of ground-water level be decided upon for the entire field, such as will most nearly approach the requirements of the majority of crops to be raised, exclusive of the true grass crops. This approximate average is evidently 3 to 3½ feet after settlement of the bog is practically complete. Hence the control tile should be placed at this depth plus the allowance for settlement of the bog—if it be a raw bog—and for a small, upward arching of the ground-water surface during protracted rainy periods. The total original depth in a raw bog at the time of installation in most cases, therefore, will amount to from 4 to 5½ feet according to the looseness of the original surface of the raw bog.

A greater refinement of control may occasionally be justified in case of bogs of limited area confined wholly to the intensive cultivation of some special crop of unusually high return per acre. In such a case a study of the results herein shown for the type of crop in question will serve as a guide to good practice.

On bogs permanently devoted purely to grass crops a depth of drainage of from 1.5 to 2.0 feet, after settlement of the bog is complete, is ample and is recommended.

SUMMARY AND CONCLUSIONS

As drainage is a prime requisite in the agricultural use of peat soils, in this experiment depths of water table 1, 2, 3, 4, and 5 feet below the surface were secured on definitely limited areas.

Control of the depth of water table on each control plot was secured by an adjustable weir in the main tile line downstream from the plot, the water being fed into the soil by a loop of 4- or 5-inch drain tile surrounding the control plot, taking off from and ending in the main above the weir.

Depth of water table was measured semi-weekly throughout each season from the tops of test wells set in straight lines across each control area at intervals shown in Figure 2. Elevation of tops of test wells was redetermined several times each season.

The data obtained showed control of the ground-water level by this method to be possible within practical limits at any desired depth below the surface, provided the peat is at least as deep as the desired water level, if there is an ample supply of underground water, and if potential settlement of the original bog surface is allowed for in the control works.

Control, however, is relatively expensive and can be justified only in the case of special crops yielding a high return per acre.

Settling of the surface of the bog continued for several seasons after cultivation began. It was practically proportional to the depth of water table maintained on the different plots. One may expect a total settlement of from 6 inches to 2 feet. Such surface settlement is one of the principal factors determining proper depth of drains in a new bog if the depth of the peat is 4 feet or more.

Over any given control area the surface of the water table tended to remain flat; but heavy rainfall caused temporary upward arching of it between tile lines, while high water requirement by the plants during July and August depressed it.

The surface was packed with a heavy roller each season before seeding or planting. The packing is essential for satisfactory seed germination. It seems also to aid in protection against summer frosts owing to better heat conductivity of the compacted peat.

Fertilizer was applied by the co-operating divisions as follows: 1925—over the entire tract, triple superphosphate at the rate of 400 pounds and muriate of potash at the rate of 200 pounds per acre; other years—for field crops, nothing, for truck crops, 16 per cent superphosphate at the rate of 600 pounds and muriate of potash at the rate of 400 pounds per acre.

For best results, careful attention to the use of fertilizer is essential on peat soils. No general rule can be given. Each bog is an individual problem for the solution of which reference is made to Minnesota Agricultural Experiment Station Bulletins 188, 194, and 292. It is also recommended that direct counsel of the Division of Soils of the Experiment Station be sought in this matter.

Crops raised were as follows: Field crops—sugar beets, field corn, flax, oats, soybean hay, and timothy and clover hay; truck crops—snap beans, sweet corn, onions, potatoes, tomatoes, carrots, summer radish, winter radish, cabbage, cauliflower, spinach, lettuce, and celery.

Summer frosts occurred nearly every summer. They seriously affected yields of those crops especially susceptible to damage by frost, notably flax, field corn, beans, sweet corn, potatoes, and tomatoes. Soybeans, usually fairly resistant to frost, were seriously damaged by both June and August frost. Frost damage was greater on the deeper controls owing to the poor heat conductance of the peat soil, indicating that as high a ground-water level as compatible with the crops to be raised is desirable as one means of protection against the summer frost menace.

Air drainage was poor especially when the wind was from a direction west of north, owing to the presence of a solid wall of timber and brush along the south and east sides of the experimental tract. That a lack of good air drainage emphasizes the frost menace is evident from the fact that after the timber on the east and south was removed, permitting free air movement over the entire region, summer frosts rarely occurred.

Yields were determined for each half foot difference in ground-water level.

Flax did fairly well the first season with best results at 3- to 3½-foot depth of ground-water. It was a failure all other seasons due largely to weed infestation altho also damaged by summer frosts which are a serious handicap with flax on peat. However, elsewhere in Minnesota, good success has been obtained with flax on peat as the first crop on any breaking. After the first crop, the weed nuisance is usually difficult to overcome. Once it is overcome, good success may be had with flax even after the first year.

Oats was not a satisfactory crop any season at any depth of drainage, which is contrary to usual experience with oats on peat except where lodging or severe rust occurs.

Hay crops, such as soybeans, timothy, and clover, did well, with best yields where drainage was not over 2½ feet deep after the bog had ceased to settle.

Spinach and head lettuce failed to give any satisfactory results. Failure of spinach, usually a reliable crop on peat soil, is not readily accounted for unless due to unseasonable planting. Climatic conditions in this region are not favorable for production of head lettuce.

After settling of the bog was complete, best results were generally obtained for all other crops in these tests with depths of water table from 3 to 3½ feet.

On peat soils a final average depth of drainage of from 3 to 3½ feet, after settlement of the bog is practically complete, is recommended where growing of almost any type of crop is apt to be tried at some time.

LITERATURE CITED

1. Alway, F. J. Agricultural Value and Reclamation of Minnesota Peat Soils. Minn. Agr. Expt. Sta. Bull. 188. 1920.
2. Alway, F. J. Report of Golden Valley Peat Experimental Fields. Minn. Agr. Expt. Sta. Bull. 194. 1920.
3. Arny, A. C., and McGinnis, F. W. Field Crop Variety Trials on The Coon Creek Experimental Fields, 1919-1925. Minn. Agr. Expt. Sta. Bull. 228, pp. 1-42. 1926.
4. Currence, T. M. The Effect of Drainage Depth on Yield and Quality of Onions when Grown on Peat Land. Minn. Hort. **59**:114. May 1931.
5. Ghostly, Geo. The Prevention of Frost on Peat Lands by Encouragement of Air Drainage. Trans. Ia. Hort. Soc. 1930, pp. 330-41.
6. Hayes, H. K., Arny, A. C., Wilson, H. K., and Powers, L. Crop Investigation on Peat Lands. Minn. Agr. Expt. Sta. Bull. 292. 1932.
7. Robertson, Ian M. The Drainage of Peat Land. Scottish Jour. of Agr., **16**: 160-172. April 1933.
8. Roe, H. B. Productivity of Peat Soil as Influenced by Height of the Groundwater Table. Proc. and Papers, First Int. Congress of Soil Sc., pp. 637-661. June 13-22, 1927. Vol. III.
9. Whitson, A. R., and Ulsperger, H. W. Marsh Soils. Wisc. Agr. Expt. Sta. Bull. 309. 1919.